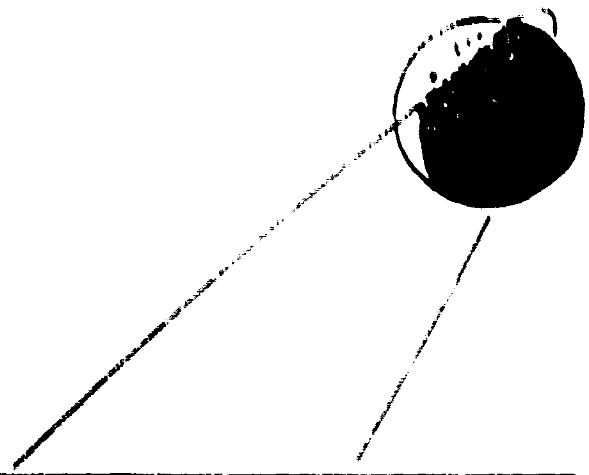


GROUND IMPACT SHOCK MITIGATION CARGO TRUCK, 3/4-TON M37

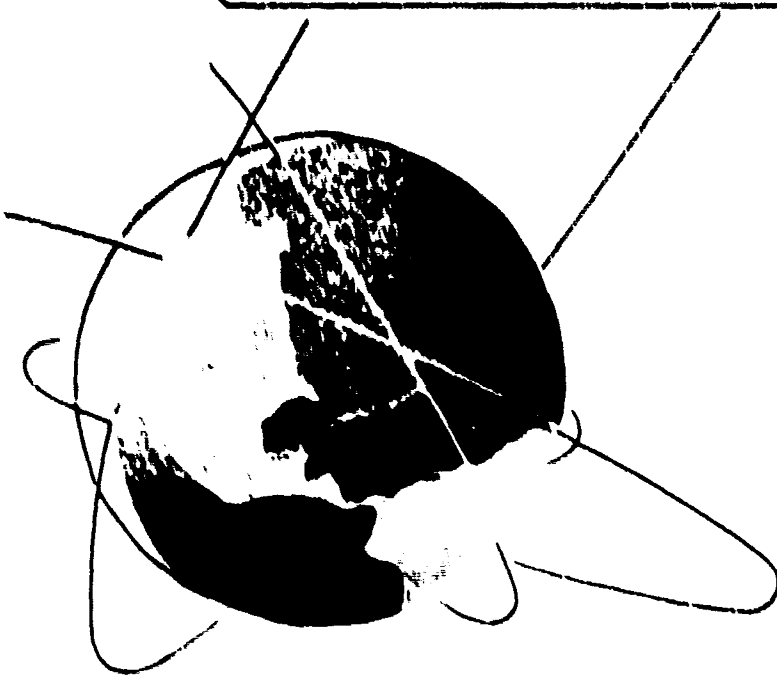
BY

D. G. WIEDERANDERS, W. L. GUYTON

AND

E. A. RIPPERGER

EMRL TR 1011 DECEMBER 1966



ENGINEERING MECHANICS RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS · AUSTIN, TEXAS

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TR 1011

GROUND IMPACT SHOCK MITIGATION

CARGO TRUCK, 3/4-TON M37

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U. S. ARMY NATICK LABORATORIES
AIRDROP ENGINEERING DIVISION

Project No. 1M141812D183

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ENGINEERING MECHANICS RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

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PREFACE

This report is the second in a series dealing with high velocity dropping of a variety of vehicles under Contract DA-19-129-AMC-582(N) with the U.S. Army Natick Laboratories. High velocity, in this case, means up to 50 fps. The first report in the series was entitled Ground Impact Shock Mitigation - M-151 Utility Vehicle (Jeep).

Both the M151 (Jeep) and the M37 3/4-ton Cargo truck were the subjects of reports issued in 1960 by the Structural Mechanics Research Laboratory under Contract DA 19-129-QM-1383 with the Quartermaster Research and Engineering Command. These earlier reports presented the results of studies of the damage susceptibilities of the vehicles when dropped at a velocity of 30 fps, which was the impact velocity specified at that time for aerial delivery. The design acceleration was 16g. Cushioning configurations which provided drive on-drive off capabilities and gave adequate protection for the specified drop conditions were developed, and described in the reports.

For the investigation described in the report presented here, the only limitation placed on the impact velocity was the limitation of the drop facility. The maximum free-fall height that could be used for the truck was about 45 feet. This gave an impact velocity of 53.5 fps. The only limitation

placed on the design acceleration was that it be the maximum the vehicle could withstand without sustaining damage that would impair its operation. For a suitable cushioning system, the maximum allowable average acceleration was determined to be 30g. No drive on-drive off capability was built into the cushioning system since this study was primarily a feasibility investigation.

Recommendations are given for changes in the design of the vehicle which will improve its resistance to damage during aerial delivery.

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December 12, 1966

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ABSTRACT

Seven drops of the M37 3/4-ton truck have been made at impact velocities up to 56 fps, and at design accelerations as high as 30g. The cushioning system used for each drop is described and the damage sustained by the vehicle is discussed. It is concluded that this vehicle can be dropped at impact velocities up to 50 fps without any damage, if a properly designed cushioning system is used.

Recommendations for improvements, from the aerial delivery standpoint, in the design of the vehicle are included. A detailed description is given of the procedure that should be followed in the design of a cushioning system.

INTRODUCTION

Twenty-five feet per second has been the nominal design impact velocity for the aerial delivery of equipment and supplies for several years. It has been shown, however, by Turnbow and Steyer[1]* that the cost of aerial delivery can be reduced appreciably by using a higher impact velocity. This saving results from the use of relatively inexpensive paper honeycomb to dissipate the energy, rather than the large expensive parachutes required to achieve the 25 fps impact velocities. In addition, a higher impact velocity reduces the dispersion of the dropped material, increases the accuracy of the drop in so far as hitting the target area is concerned, and, because of the reduced time that the equipment is in the air, reduces the danger from possible enemy action.

In theory, at least, it is possible to cushion a vehicle so that it will survive an impact of any velocity, but there are other considerations. For example, the space available in aircraft is limited. This obviously places a limit on the impact velocity that can be sustained because the volume of cushioning material increases with the square of the impact velocity. In addition, the stability of the cushioning system becomes a serious problem as the height of the cushioning stack increases.

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*Superscript numerials indicate references listed at the end of the report.

In order to study some of the practical problems of cushioning vehicles against high impact velocities; to discover some of the hidden problems; and to determine the maximum practical impact velocity for a specific vehicle; the program of drops of the M37 Cargo Truck, which is reported here, was undertaken.

The primary objectives of this investigation have been

1. to verify that the vehicle could be successfully dropped at impact velocities as high as 50 fps,
2. to determine the design acceleration that would be required for such a drop,
3. to work out the essential details of a prototype cushioning system, and
4. to observe the damage susceptibility of the vehicle.

The collection of data regarding the damage susceptibility of certain specific vehicles is but one phase of the research program which is intended eventually to put the design of cushioning systems for the aerial delivery of equipment on a firm engineering basis. However, a standard cushioning system applicable to all vehicles is not feasible. Hence, each vehicle must have its own system, and although these differ somewhat in detail, they should all conform to the basic principles of cushioning design as those principles are now understood.

PROCEDURE

The approach employed was to start with a 20g acceleration and a drop height of 10 ft, and to gradually work up to higher impact velocities and design accelerations.

A cushioning system had been developed for this vehicle five years previously by this laboratory.[2] That cushioning system was used as a basis for the initial drops. Several changes were made, however, to correct some of the defects noted in the earlier drops and to provide additional support in the critical areas.

The vehicle used for this series of drops was an M37, 3/4-ton, 4x4 Cargo Truck supplied by the U.S. Army Tank-Automotive Center under arrangements made through the U.S. Army Natick Laboratories.

The truck was tested in the "as-received" condition except for the following modifications:

1. Windshield removed
2. Cab removed
3. Outside mirror removed
4. Lifting wheel plates installed
5. Three accelerometers, one each, installed on the winch, the engine, and the rear frame cross member.

The first four modifications were made to allow room for the lifting apparatus, and the last to provide acceleration data for comparison with the design acceleration and for possible correlation with observed damage.

Prior to the initial drop of the M37, the available honeycomb cushioning material was tested to determine the average crushing stress and energy-absorption characteristics. Tests were also made to investigate more critically the effects of increased stack heights on the energy absorption and stability characteristics of honeycomb stacks during crushing, and the effects of load spreaders placed in a crushing stack to provide more uniform crushing.[3]

The results of these tests provided guidance for the development of an effective cushioning system for the M37 and will be used for designs involving other test vehicles.

Drop Program

The program followed in this test series called for the first drop to be from a height of 10 ft with a design acceleration of 20g. In subsequent drops, both the height and design acceleration were increased as seemed warranted by the results of previous tests. This was to allow an effective cushioning system to be designed and tested at lower impact velocities before relying on the system at the high impact velocities and accelerations required in the later phases of the program. By this plan, it was hoped that the limits of the vehicle could be approached without critically damaging the vehicle. Hence the initial drop was designed for 10 ft and 20g with each succeeding drop designed to either test changes in the cushioning system or to proceed to the next higher drop velocity.

In preparing for the initial drop, a weight distribution for the truck and 1500-lb simulated load of sandbags was calculated. The initial cushioning configuration was then designed using this distribution and the results of the early drop series previously mentioned.[2] Allowance was made in the design of the cushioning system for some of the energy of the drop to be absorbed in the spring-shock absorber system of the vehicle.

Typical design calculations are shown in the appendix.

Problems Encountered

Some of the problems encountered were:

1. Difficulty in cushioning the engine adequately.
2. Weak center cross members in the frame.
3. Insufficient area under bed and rear of the truck to cushion effectively.

The last two of these problems were solved by the use of two loadspreaders. Because of their complexity, the fabrication of these loadspreaders may not be practical from the field users standpoint. Consequently, further study is needed to reduce the complexity of these loadspreaders and to provide an effective system that is both simple and economical for use at high impact velocities. However, since the primary objective of this study was to determine the feasibility of dropping at impact velocities up to 50 fps rather than the development of an ultimate system suitable for field use, no attempt was made to refine the design of the loadspreaders. With the prototype system described in this report for guidance, the development of a system for field use should not present any significant difficulties.

Lifting Rig

The M37 truck used for this test series was rigged for drop by attaching lifting plates and shackles to each of the wheels. To facilitate the lifting and leveling of the vehicle, chains were attached to one end of each of four slings. One of these chains was passed through each shackle and hooked back on itself. This allowed for quick adjustment of each wheel independently to achieve a level attitude of the vehicle.

The four sling ropes were separated by spacer beams to prevent damage to the vehicle, and attached to a large lifting shackle. This shackle was engaged by a helicopter hook which was released for the drop by the Fastax-Camera timing control. The entire rigging is shown in Fig. 1.

In previous drops, the wire rope used was at least 1/2 in. in diameter. A wire rope of this size is extremely stiff and difficult to handle. Thus leveling of the load is slow and difficult. Consequently, the 1/2-in.-diameter ropes were replaced with 1/4-in. wire ropes with a rated strength of 5500 pounds. This provided a safety factor of two in the lifting arrangement. The 1/4-in. ropes failed disastrously, however, in the first test and were replaced by 3/8-in. ropes for subsequent drops.

Platform

An 8×16-ft plywood platform was designed and built, essentially to the specifications for the combat expendable

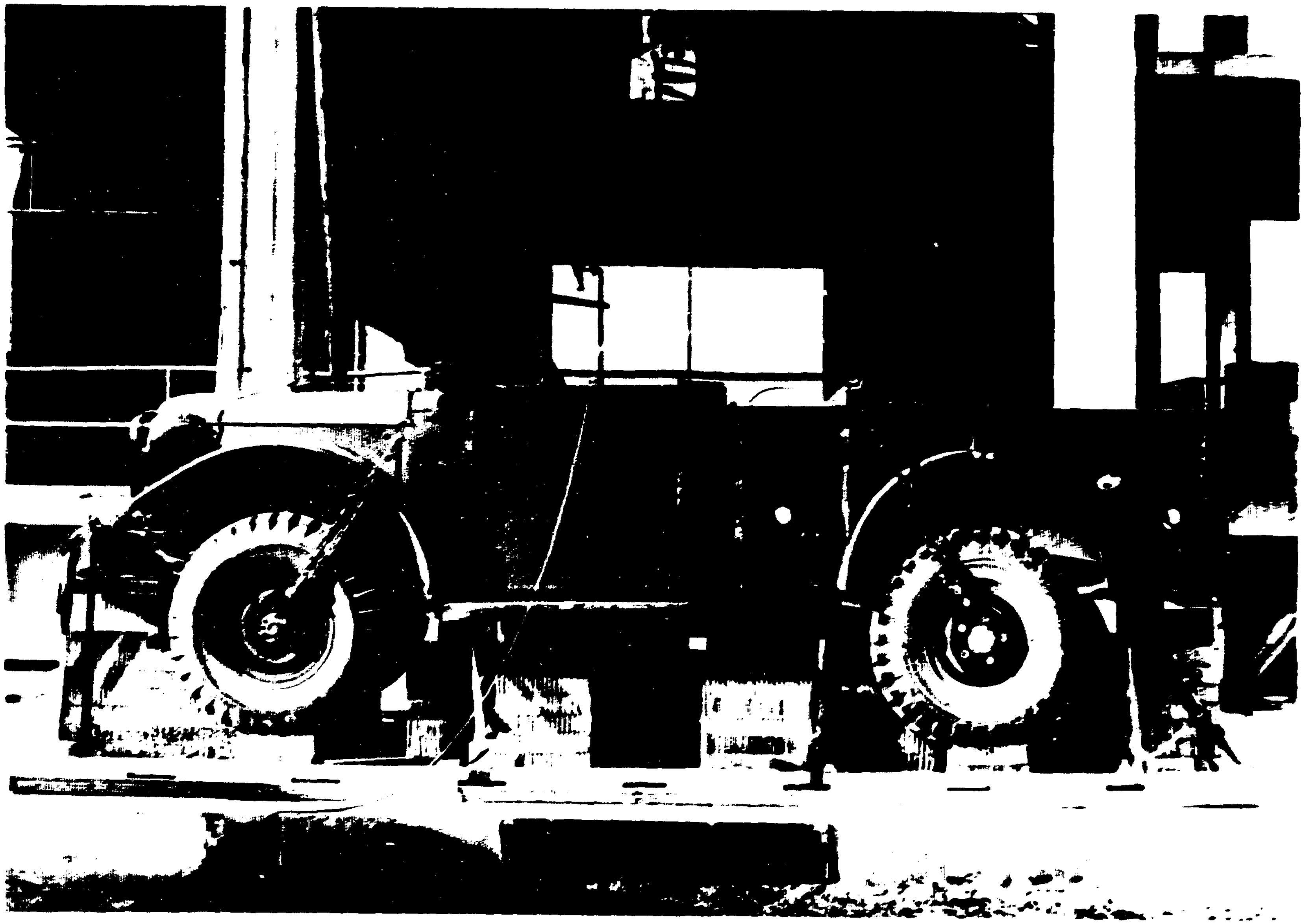


Fig. 1 Rigging for Lifting the Vehicle

platform described in TM 10-500-13. This platform performed very well and has been damaged only slightly by the seven drops in this series.

Honeycomb

The cushioning material used throughout this series was 80-0-1/2 paper honeycomb purchased directly from the manufacturer. The average crushing strength and energy-dissipation characteristics of this honeycomb had previously been determined to be 8090 lb/ft^2 and 5660 $ft\text{-}lb/ft^3$ respectively.[3] An initial series of tests prior to the start of the drop-test program substantiated these figures, which were then used in the design calculations for drops M37-1 through M37-5. After subsequent honeycomb testing, it was determined that as the stack height increased, the nonuniformity of crushing increased and the average crushing stress decreased. The average crushing stress determined for stacks which were 24 in. high was 6430 lb/ft^2. This value was used for drops M37-6 and M37-7. If 3/4 in. thick sheets of plywood are inserted in the stack at 6 in. intervals, the uniformity of crushing is greatly improved and the average crushing strength is increased from 6430 lb/ft^2 to 6590 lb/ft^2.

Instrumentation

Accelerometers were mounted on the vehicle in the following positions: winch housing, engine, and rear area. For Drops 1 through 4, the rear accelerometer was mounted directly on the rear frame cross member. Upon impact, this member underwent

considerable vibration and as a consequence, meaningful data could not be obtained from the accelerometer mounted on the member. After Drop 4, a large 1-1/2-in. thick steel plate was bolted through the load pallet in the bed of the truck and the accelerometer was mounted on this plate. This greatly reduced the vibration amplitude indicated by the accelerometer.

In addition to acceleration records which were recorded by both an oscillograph and magnetic tape system, high-speed motion pictures were made of all drops. These pictures were studied for an indication of the efficiency of the cushioning and for clues as to what changes should be made to improve the performance of the system. Prior to each drop, and at the completion of each drop, documentary photographs were also made. After a drop, the vehicle was carefully examined for any visible damage and then it was road-tested.

SUMMARY OF DROP PARAMETERS AND DAMAGES OBSERVED

M37-0-Height 10 ft; Acceleration 18.5g

The first scheduled drop was designed for a 18.5g acceleration and a drop height of 10 feet. To keep the bending moments in the truck small, the cushioning system was spread out as much as possible and point loads were opposed directly with cushioning forces. Following these guidelines, the cushioning stacks were placed so as to provide a 18.5g deceleration with zero moment about the truck center of gravity during impact.

As related previously, the sling system with 1/4-in. wire ropes was designed for a safety factor of two. During final preparation for the drop when the truck was being raised, the Varidrive motor and hoisting winch stalled when the truck was 9 ft above the concrete slab. As the winch was being restarted, the left rear sling cable broke, forcing the left front and right rear cables to take all the load. These two immediately broke as did the right front a moment later, and the truck and platform fell. The left rear of the system hit first, the platform split longitudinally, and the truck came to rest on its left side as seen in Fig. 2. Very little crushing of cushioning pads occurred.

After the truck was righted and inspected, the damages were seen to include:

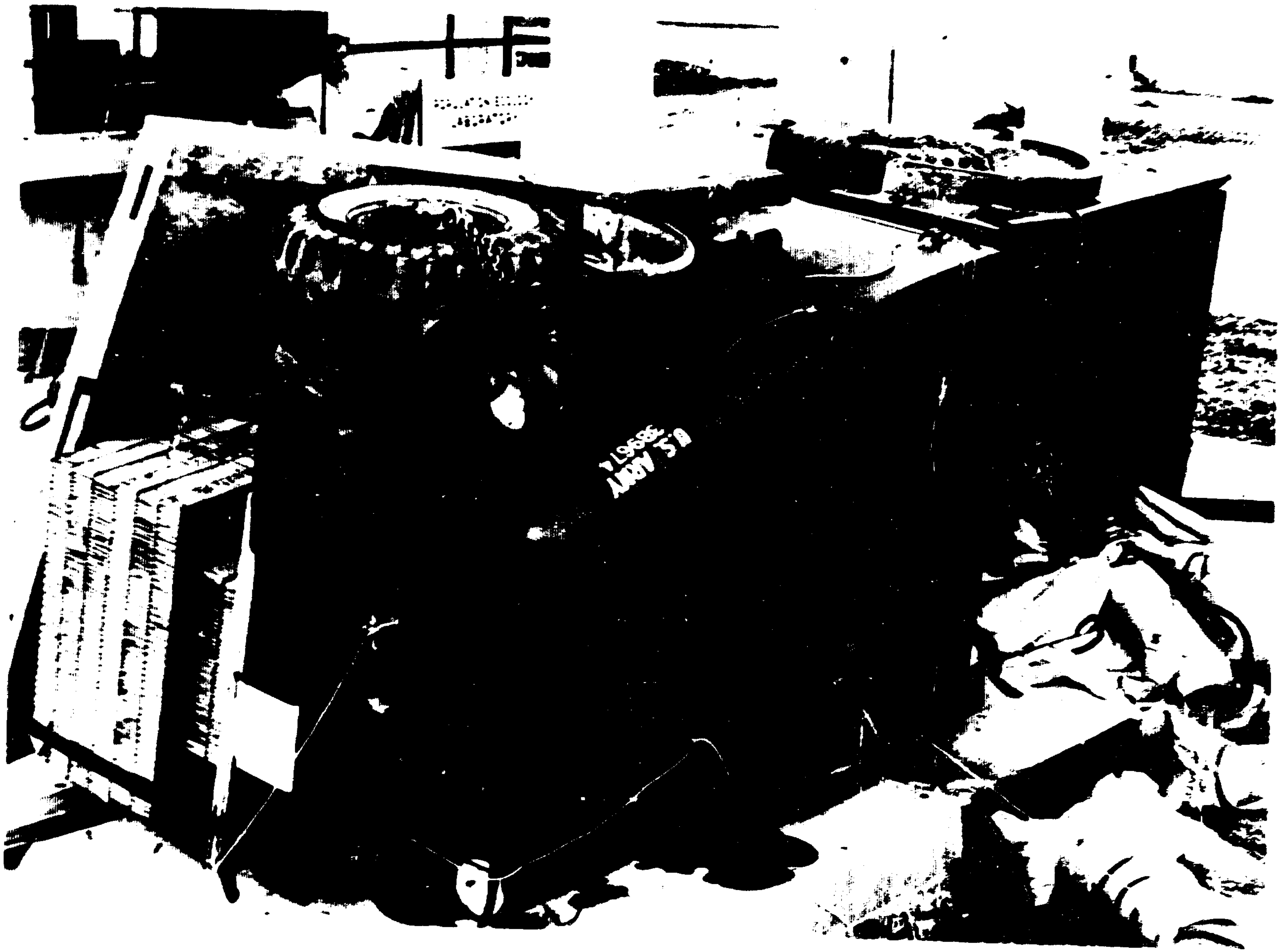


Fig. 2 Truck After Drop M37-0

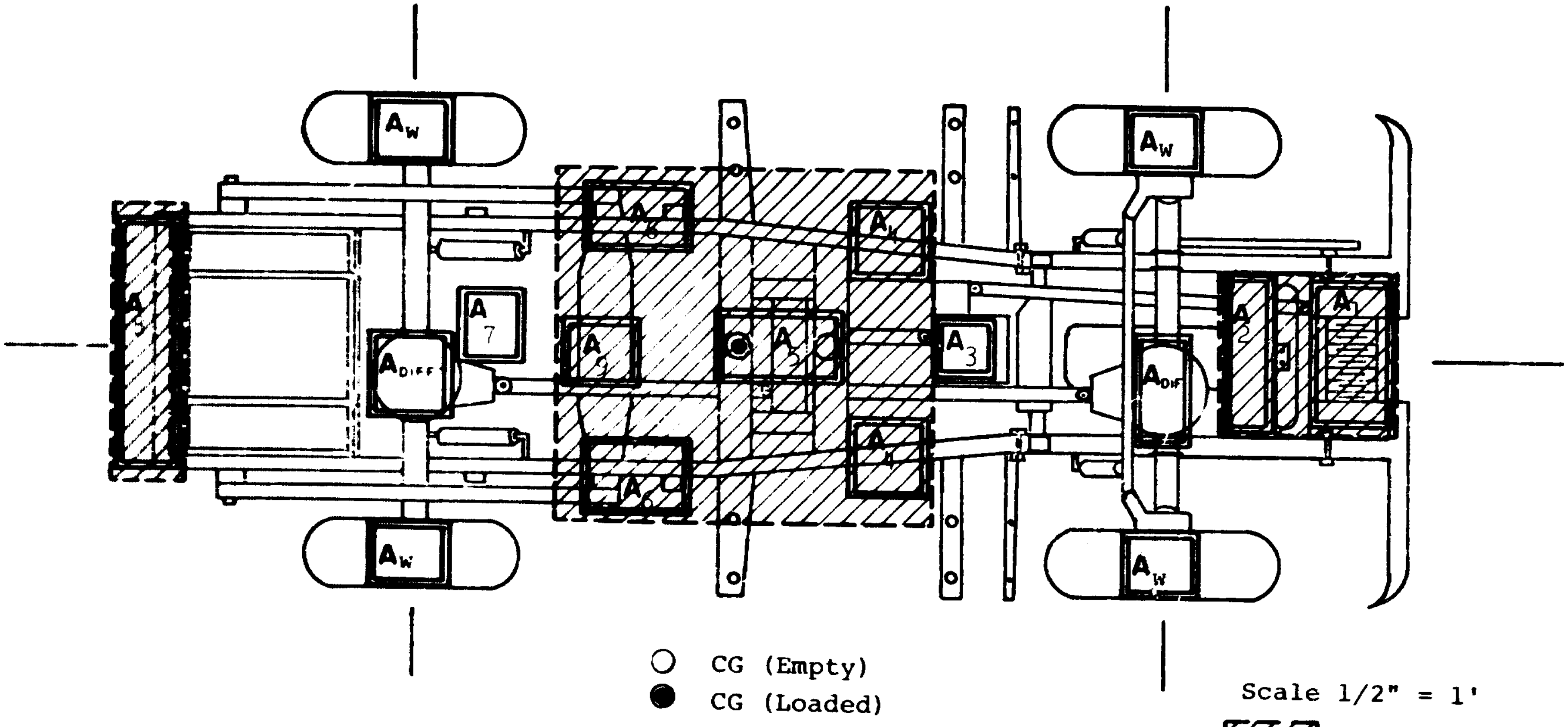
1. The grease shield on the crankshaft pulley was bent so as to rub on the front motor mount cross member.
2. The front left and right rear fenders were slightly dented where the cables wrapped around the truck during the fall.
3. The left rear wheel was slightly bent.

Once the grease shield was removed from the truck and the left rear wheel replaced with the spare, the truck operated satisfactorily.

The cables were inspected for flaws and tested for strength, but nothing was found that would indicate the cables were at fault nor was anything else in the system found to be at fault. The apparent reason for the cable failure was the uneven loading in the cable strands in the region of the rigging standoffs. For subsequent drops, cable size was increased to 3/8-in. to provide a safety factor of four.

M37-1-Height 9 ft; Acceleration 18.5g

The design acceleration for this drop was 18.5g at a drop height of 10 feet. Placement of the cushioning stacks is shown in Fig. 3. This drop was made from a height of 9 ft because the hoisting winch stalled at that height. The truck was then dropped from that height. Consequently, the impact velocity was 24 fps rather than 28.4 fps. The average acceleration as measured on the engine was 18.1g.



Stack Areas and Heights Shown in Table I

Fig. 3 Cushioning Arrangement for M37-1
Total System Height 72-1/2 inches including Honeycomb Crushing Stacks

Table 1

Drop M37-1

Position (See diagram)	Stack Area	Height
wheel	0.865 ft^2	9 in
f.d. (front differential)	1.08 ft^2	9 in
1	1.92 ft^2	9 in
2	1.2 ft^2	9 in
3	0.5 ft^2	9 in
4	1.76 ft^2	9 in
5	1.31 ft^2	9 in
6	1.7 ft^2	9 in
7	0.75 ft^2	9 in
r.d. (rear differential)	1.08 ft^2	9 in
8	2.24 ft^2	9 in
9	0.6 ft^2	9 in

Total System Height = 72-1/2 in

Including Honeycomb Crushing Stacks

During the impact the central load spreader (See Fig. 3) interferred with and bent the main drive shaft as shown in Fig. 4, and the 1500-lb dead load of sand in the bed of the truck severely bent the bottom of the bed and its supporting cross members. After the drive shaft was straightened, the vehicle performed satisfactorily in a road test.

A study of the high-speed movie of the drop indicated that the energy stored in the springs, because the lifting was done on the wheels, was having an undesirable effect. When the truck was released for the fall, the springs and the wheels forced the cushioning system and the truck apart by several inches, and tilted the platform slightly with respect to the ground. There may have also been displacement of some of the cushioning stacks from their intended positions with respect to the truck.

To correct the deficiencies in this drop, the following steps were taken prior to M37-2:

1. A loadspreader, consisting of two pieces of 3/4 in. plywood cut to fit inside the bed of the truck and glued together for strength, was used to prevent further damage in that area of the vehicle.
2. The central loadspreader was modified so that the drive shaft would not come in contact with it as the cushion crushed.
3. The cushioning system was designed so both the truck and the platform would maintain contact with the cushioning stacks during the fall.

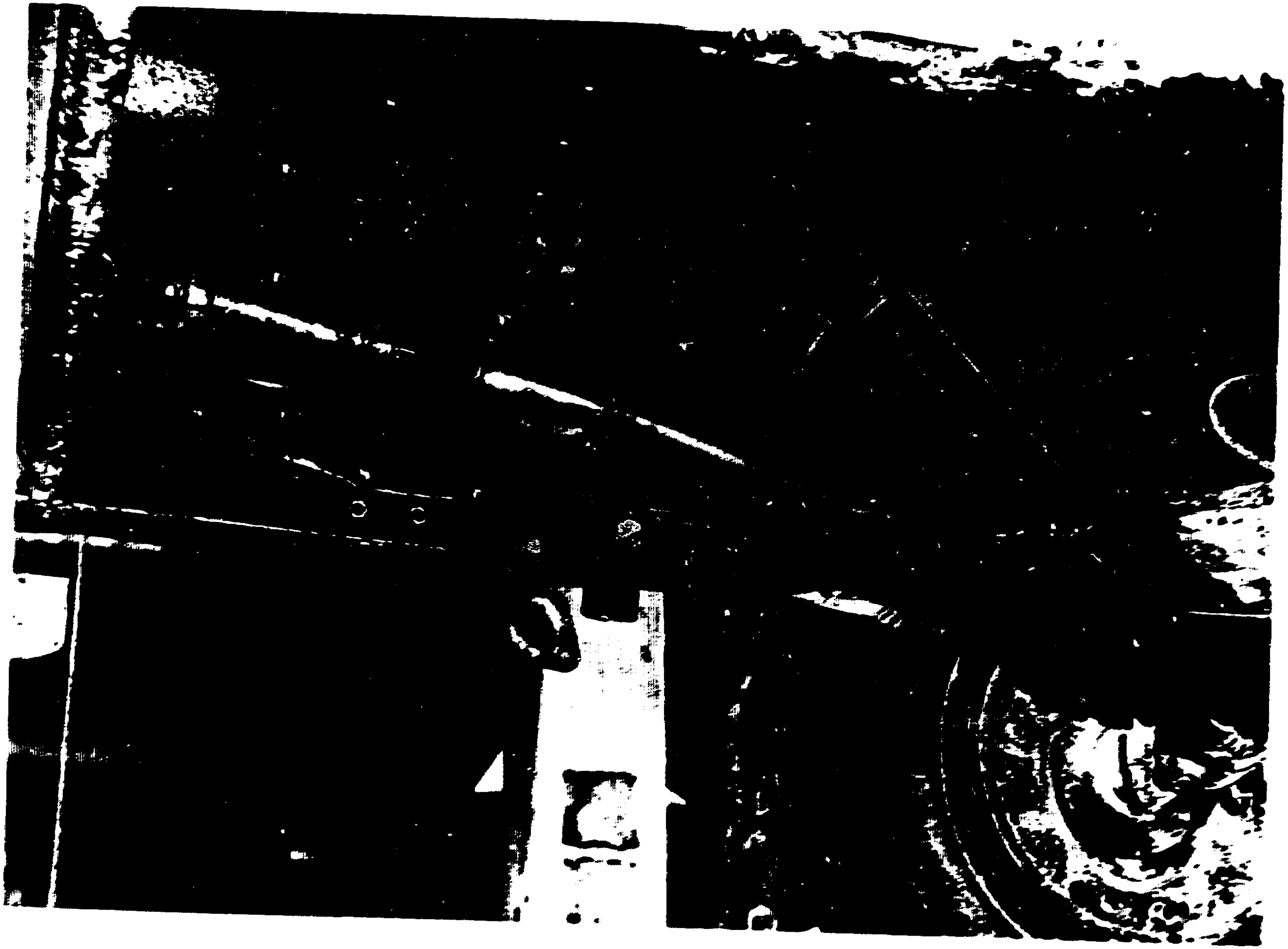


Fig. 4 Drive Shaft Bent During M37-1

M37-2-Height 20 ft; Acceleration 18.5g

Essentially the same cushioning arrangement used for M37-1 was used for M37-2 except that the compression of the springs at release was taken into account when calculating stack heights. The system was designed so that when the vehicle was released, the wheels would move far enough as the springs relaxed to just be in contact with the wheel cushions. The crushing stack heights were also increased enough to provide for the absorption of the additional energy of a 20-ft drop.

During impact, the rear cushioning stack buckled. Apparently the resultant load on the stack was applied slightly off center. Since the stack was ineffective in supporting the back of the truck, both side frame members bent at a point just in front of the rear wheels. The results are illustrated in Fig. 5. Inspection and road test of the truck showed no other evidence of damage, and the bent frame did not appear to affect operation.

The load spreader, installed in the bed of the truck was very effective in reducing damage to the bed, and was used for all subsequent drops.

The high-speed movies showed that proper allowance had been made for the initial compression of the springs. This clearance was used on subsequent drops.

An attempted high-speed movie of the engine displacement was a failure because the truck missed the intended impact area enough to put the target spot on the engine out of the rather narrow field of view of the camera during the impact.

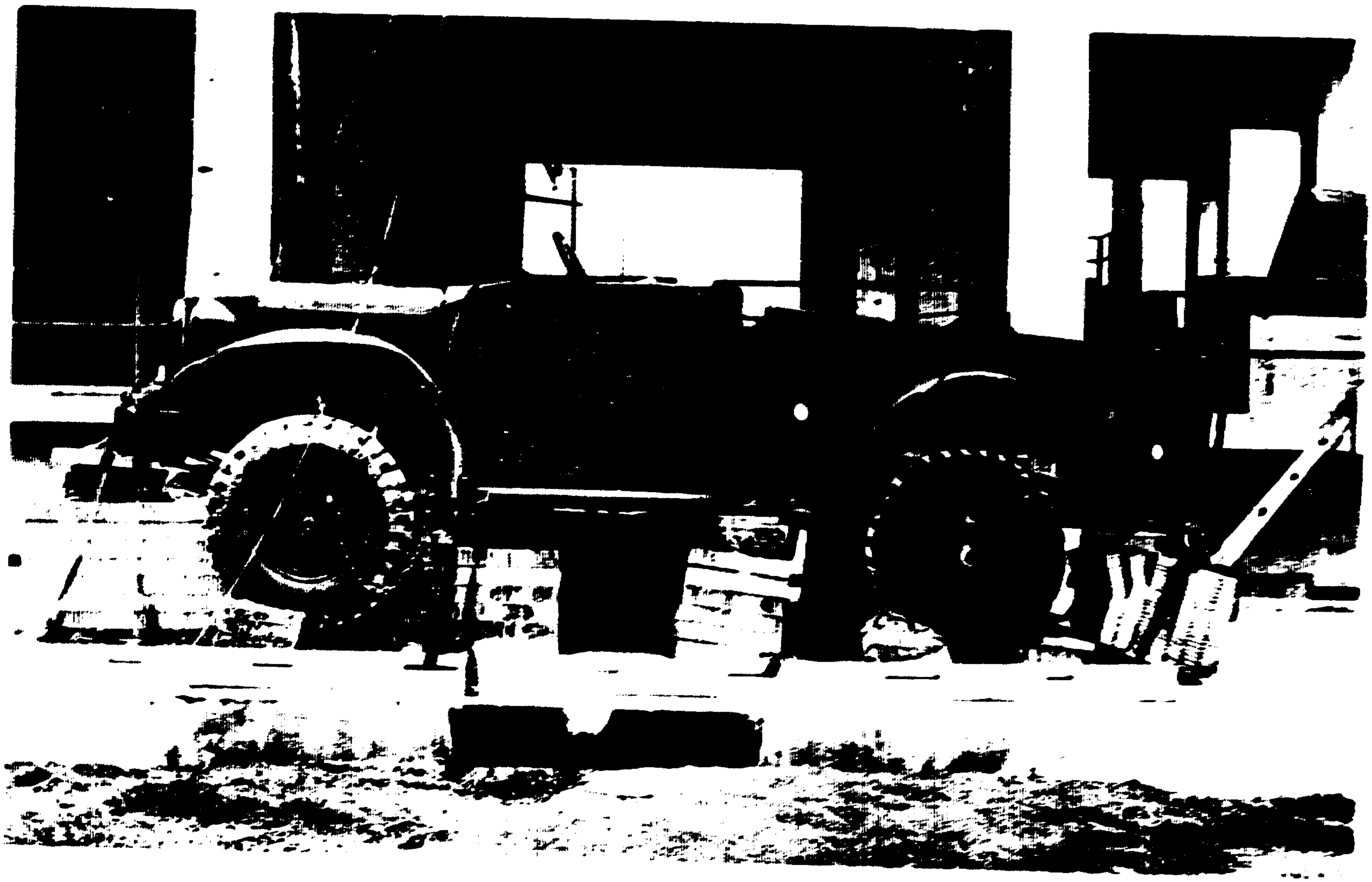


Fig. 5 Bending of Main Frame During M37-2

The average measured acceleration of the engine was 24.6g.

The following changes were made before M37-3:

1. The build-up stack for the rear cushioning system was redesigned and moved forward slightly.
2. Tie-together bridges of honeycomb were designed to stabilize the rear stack during drop and impact.

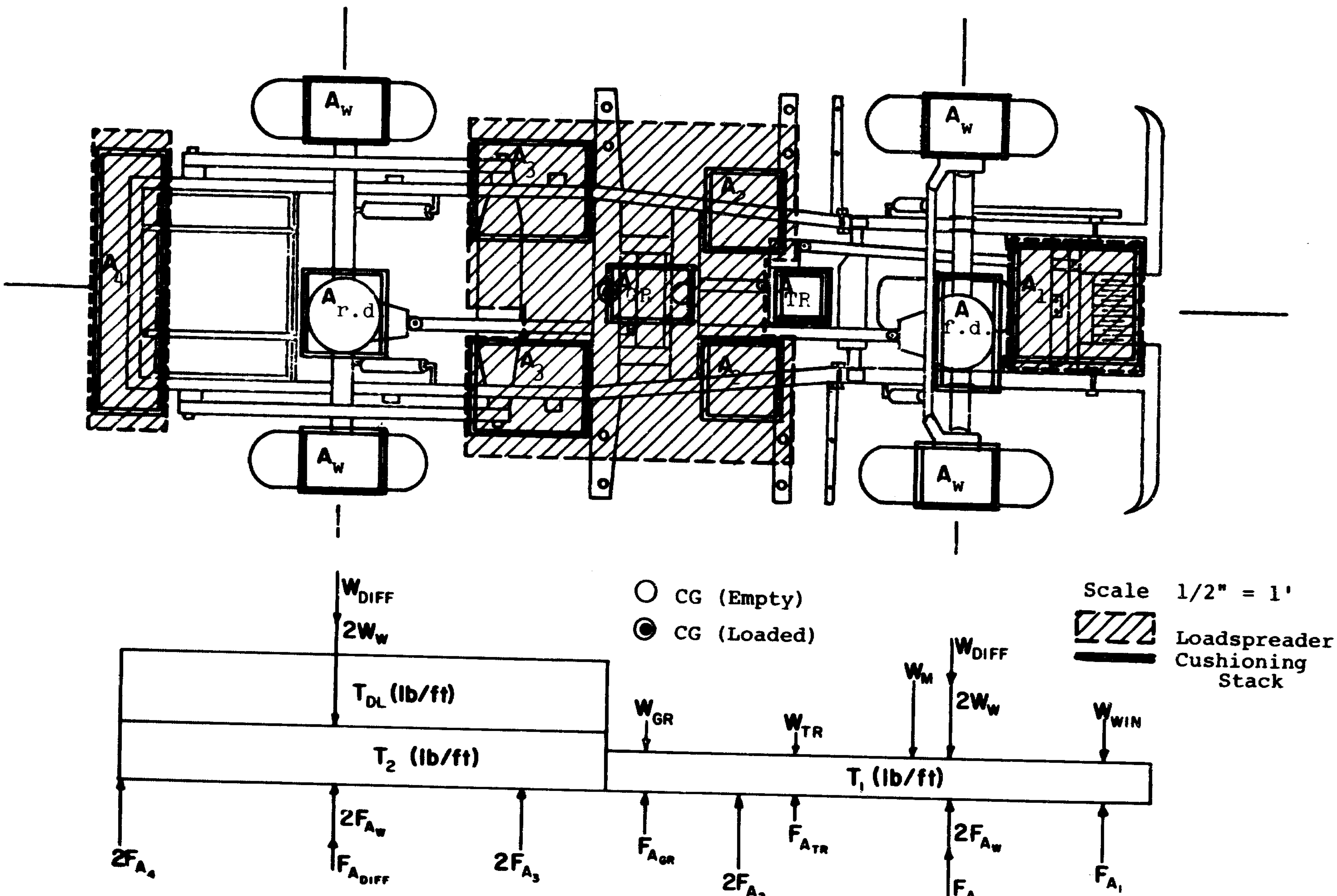
M37-3-Height 20 ft; Acceleration 27.5g

The cushioning system used for M37-1, and M37-2 was redesigned to combine several of the smaller cushioning stacks, thereby reducing the total number of stacks and increasing stability. A plan view of the stack placement is shown in Fig. 6.

Observation of this drop revealed that the rear cushioning stack did not crush to the desired percentage, thus suggesting that this stack might be overdesigned. Further inspection showed that the side frame members had been bent. This bending, however, straightened the bending noted in M37-2.

Fastax 16mm film coverage of the engine displacement during impact showed a total movement of 1 to 1-1/4 inches.

Due to a malfunction in the electronics multiplexing system, acceleration data were not obtained. This system was used to reduce the number of wires between the vehicle and the instrumentation trailer. Its use was discontinued after this drop.



Stack Areas and Heights Shown in Table II

Fig. 6 Cushioning Arrangement for M37-3
Total System Height 75-1/2 inches

Table II

Drop M37-3

Position (See diagram)	Stack Area	No. of Pads = Height
1	3.59 ft^2	4 = 12 in
2	1.53 ft^2	4 = 12 in
3	2.83 ft^2	4 = 12 in
4	4.53 ft^2	4 = 12 in
Tr (transmission)	0.74 ft^2	4 = 12 in
G.R. (gear reducer)	1.10 ft^2	4 = 12 in
wheel	1.29 ft^2	4 = 12 in
f.d. (front differential)	1.78 ft^2	4 = 12 in
r.d. (rear differential)	1.78 ft^2	4 = 12 in

Total Height of Vehicle = 75-1/2 in

M37-4-Height 20ft; Acceleration 27.5g

For this drop, the cushioning system was redesigned to increase the support for the load bearing area of the truck. The rear cushioning stack was divided and moved forward under the gas tank. A loadspreader transferred the load from the side frame members to these stacks.

The system crushed uniformly to 65 per cent with the exception of the rear stack which crushed to only 50 per cent. A view of the cushioning system after the impact is shown in Fig. 7. The front loadspreader was broken during impact. No truck damage was found during the inspection or road test.

After this drop, it was noticed that the fan-belt pulley on the crank shaft rubbed the frame cross member when the hand brake was applied. This was due to the small clearance between the pulley and frame and the movement of the engine on its mounts when the hand brake was applied.

Some acceleration data were lost due to a malfunction in the amplifier system, but the average acceleration of the engine was approximately 18.6g.

Although the resultant cushioning system reaction was moved 6 in. forward to reduce the resultant moment observed at impact in M37-3, some evidence of a resultant moment was still present in this drop.

M37-5-Height 30 ft; Design Acceleration 27.5g

For the previous drops, the weights and the CG location

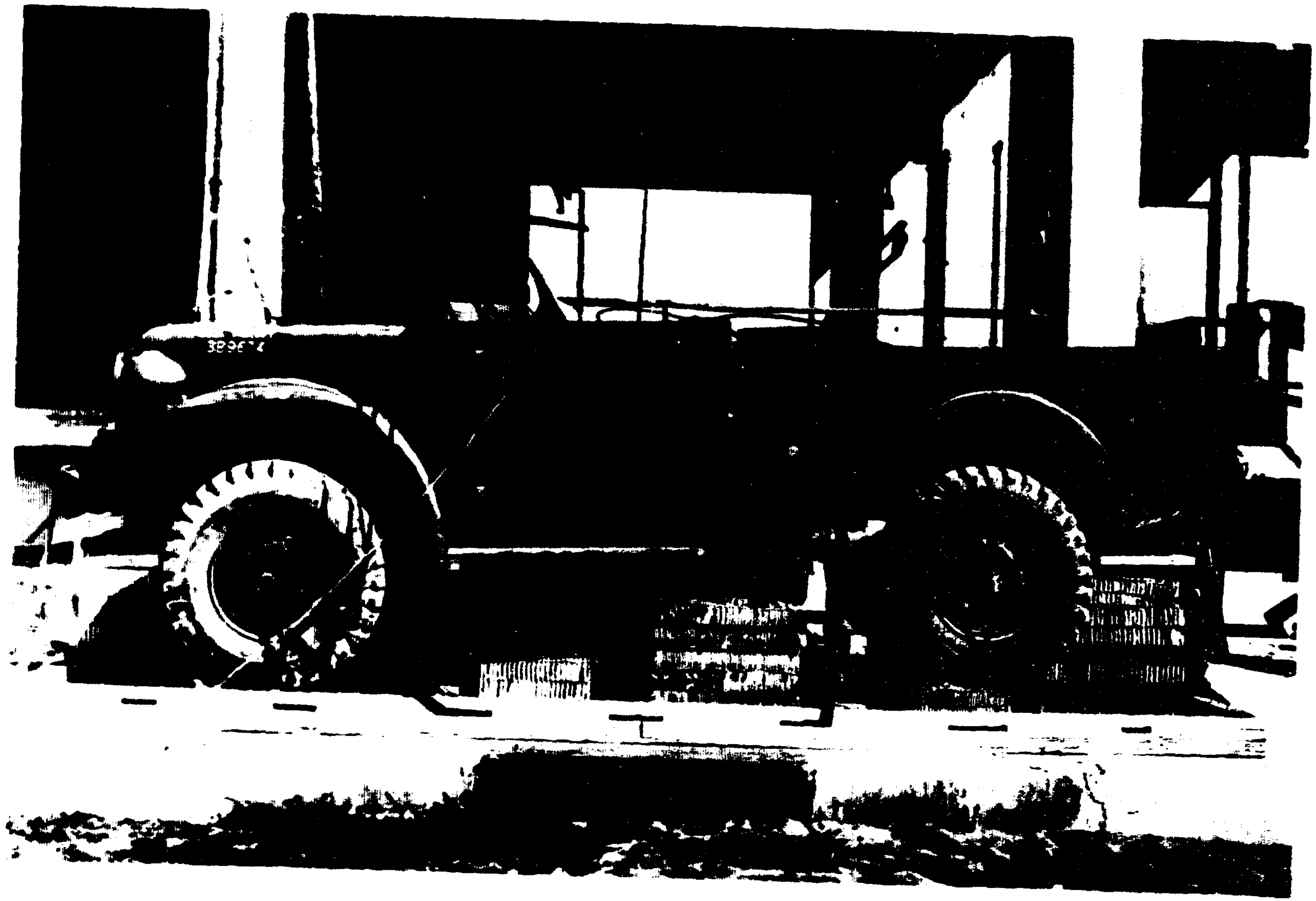


Fig 7 Cushioning After the Impact of M37-4

given in the technical manual were used for the design of the cushioning system. The nonuniform crushing observed in these drops, even though the design CG was shifted, suggested that perhaps the weights given in the TM were incorrect. Consequently, the truck was weighed with the results tabulated below.

	Tech. Manual	Weighed
Front	3251.16	3056 lb
Back	4166.16	3794 lb

The cushioning system was redesigned on the basis of these results.

Although the cushioning system reaction was again moved forward slightly to decrease the resultant moment, the drop films indicated a slight pitching of the truck during impact.

The average acceleration of the engine was 18.6g.

M37-6-Height 40 ft; Design Acceleration 30g

For this drop, the cushioning system was redesigned using slightly modified values for the average crushing stress and energy-absorption characteristics of the honeycomb as indicated by the latest results from the honeycomb test program. To eliminate the pitching seen in M37-4, the cushioning system resultant was moved forward 6 inches.

The system crushed uniformly to 70 per cent with the exception of the front stack. The action of this stack was abnormal due to a wheel stack shifting after release and providing

Fig. 8 Non Uniform Crushing of M37-6

no support to the left side. (See Fig. 8). As a result, the front engine support cross member was bent extensively, and the crankshaft pulley was bent so that it rubbed against the support member.

Upon close examination of the truck, it was observed that the left support member of the gear reducer housing was slightly bent. It could not be determined if this damage was due to M37-6 or whether it was a progressive failure brought on by the previous drops. This damage, however, had no apparent effect on the operation of the vehicle.

Immediately after the impact, a peculiar noise was heard coming from somewhere in the truck. Before the source of the noise could be located, it stopped.

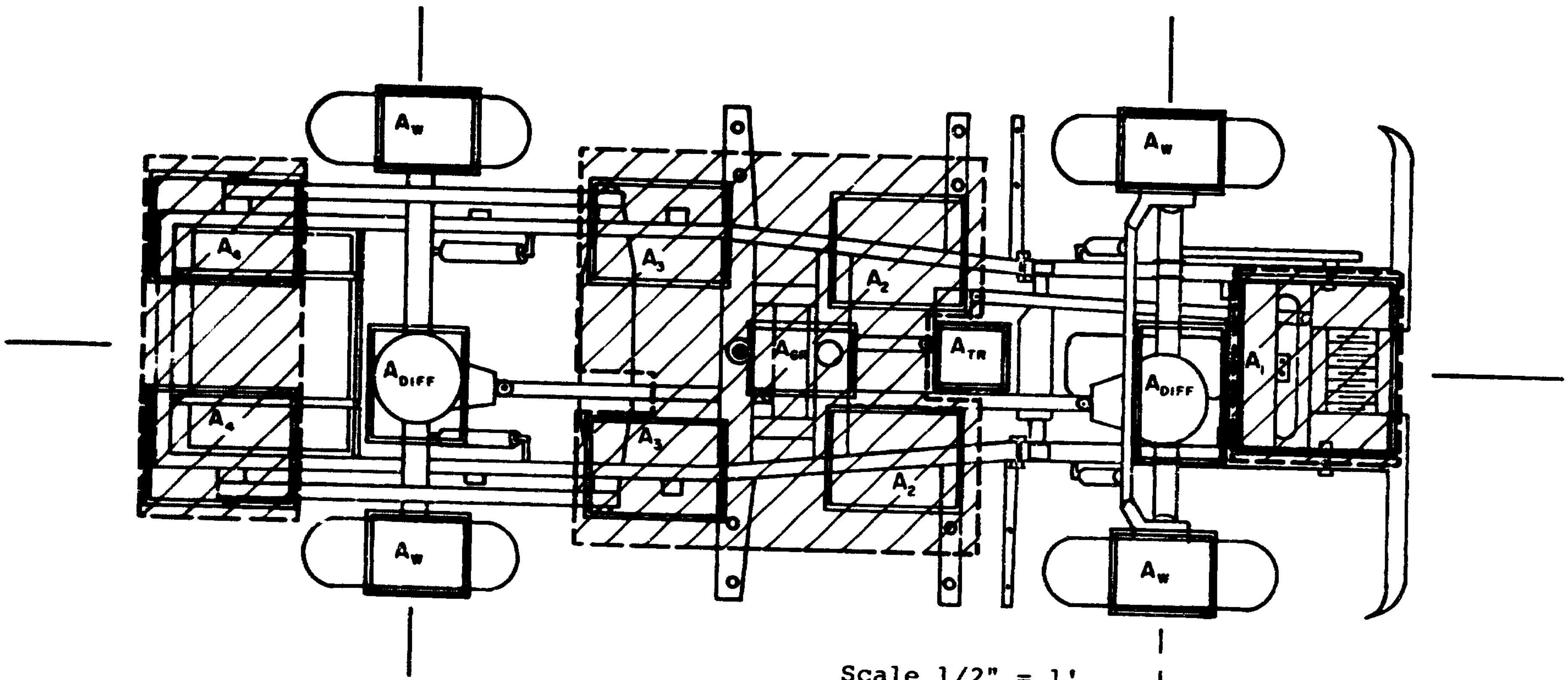
Although the truck was damaged slightly, there was no problem encountered with the cushioning system design with the exception of the wheel stack shifting.

There was no pitching of the truck during impact.

The average acceleration of the engine was 24.6g.

M37-7-Height 45.5 ft; Design Acceleration 30g

The same cushioning configuration used for M37-6 was used for M37-7 with one exception. The wheel stacks were stabilized by surrounding the crushing stack with a rectangular cutout in the middle to accommodate the crushing stack. A plan view of the cushioning arrangement is shown in Fig. 9 and a photograph of a wheel cushion is shown in Fig. 10.



Scale 1/2" = 1'

○ CG (Empty)

● CG (Loaded)

Loadspreader

Cushioning Stack

Stack Areas and Heights Shown in Table III

Fig. 9 Cushioning Arrangement for M37-7
Total System Height 87-1/2 inches

Table III

Drop M37-7

Position (See diagram)	Stack Area	Height
1	4.26 ft^2	2 ft
2	2.42 ft^2	2 ft
3	2.78 ft^2	2 ft
4	2.71 ft^2	2 ft
Tr (transmission)	0.9 ft^2	2 ft
G.R. (gear reducer)	1.36 ft^2	2 ft
f.d. (front differential)	2.07 ft^2	2 ft
r.d. (rear differential)	2.07 ft^2	2 ft
wheel	1.55 ft^2	2 ft

Total Height of Vehicle = 87-1/2 in

Fig. 10 Wheel Cushion Arrangement - M37-7

The cushioning system crushed uniformly and evenly to approximately 70 per cent. There was no pitching of the truck during impact. The vehicle is shown before the impact in Fig. 11 and after the impact in Fig. 12. The uniformity of the crushing evident in this photograph is particularly noteworthy because the wind velocity during the drop averaged 20 mph with gusts to 30 mph. The drop was made purposely under these conditions to see how much effect the wind would have.

The average acceleration of the engine was 24.4g.

Immediately after the impact, the same noise heard after M37-6 was heard. This time it was traced to the generator. The generation cutout contacts in the voltage regulator had apparently been closed by the impact and then welded by the heavy current flowing in the circuit. The contacts had to be forced apart. Quick action had to be taken to avoid completely discharging the battery since the generator, when not running, acts as a dead short across the battery. If this had happened during actual vehicle drops under combat conditions, it would no doubt, have immobilized the vehicle until a freshly charged battery could be supplied.

The truck was examined thoroughly after this drop to be certain that no damage was overlooked. It was found that the gear-reducer housing support was bent an additional amount, but no other permanent damage was found.

With this drop, the M37 series was concluded. Although no major damage resulted from these drops, it is evident from

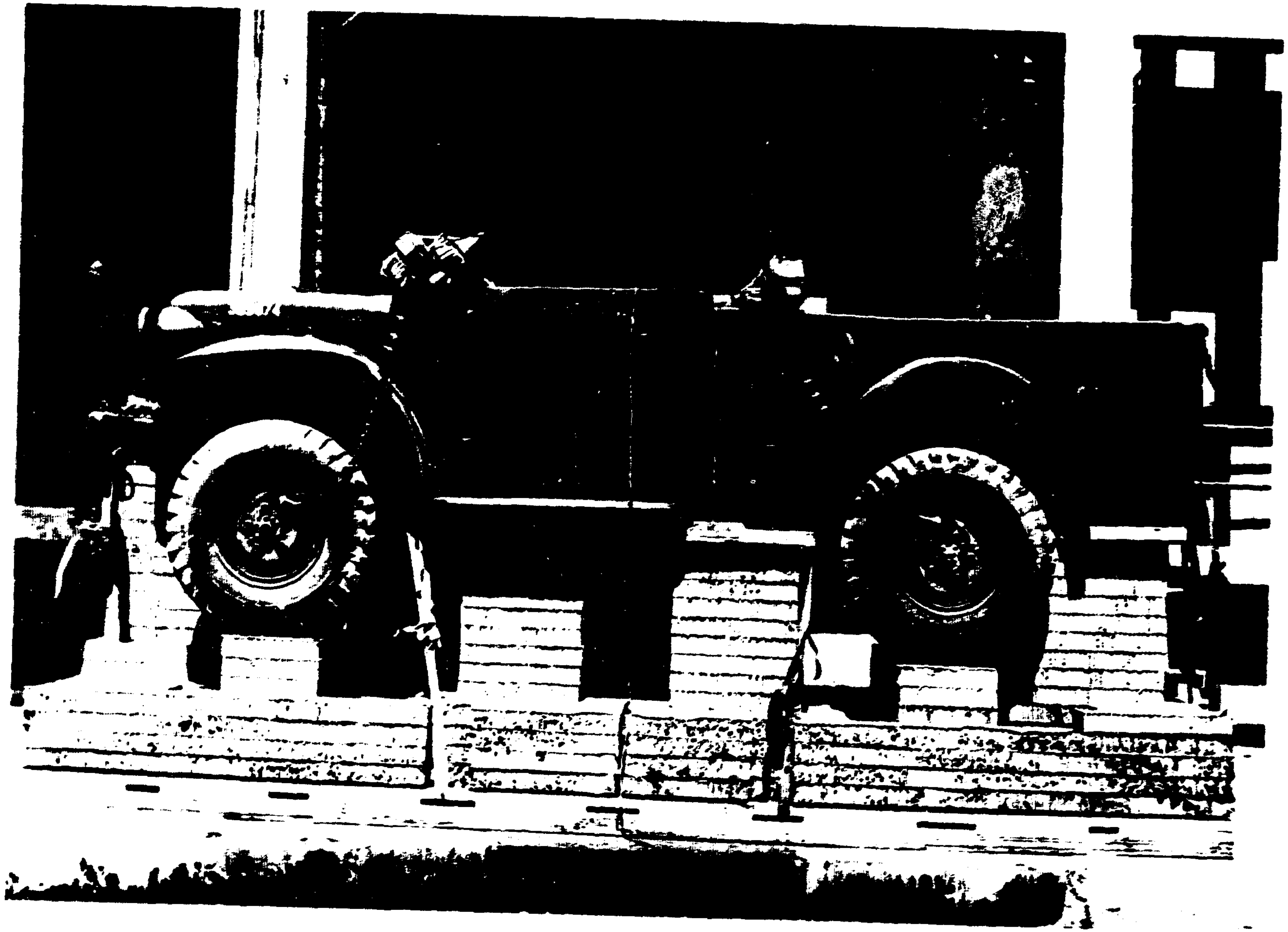


Fig. 11 Cushioning System Before Impact - M37-7

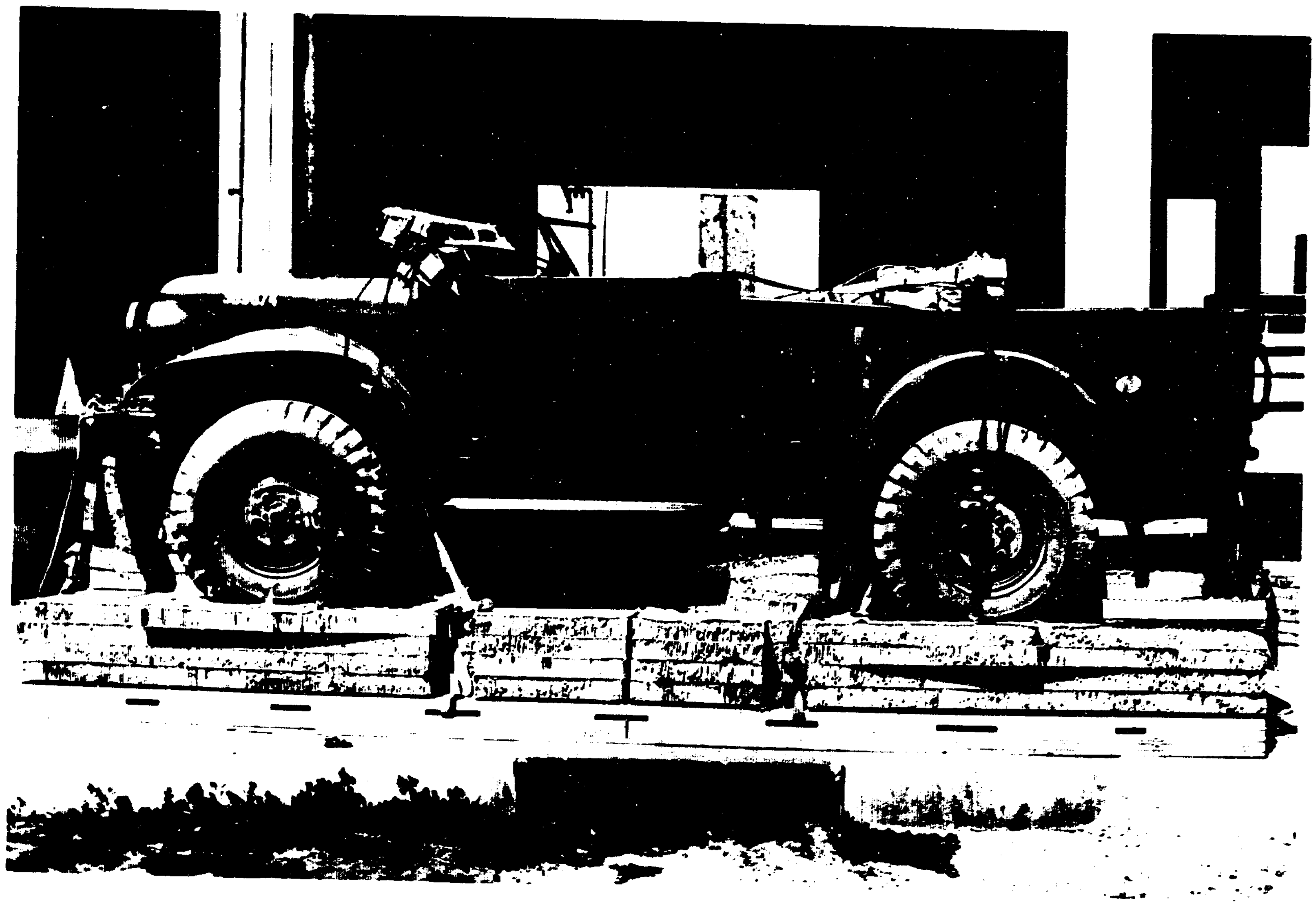


Fig. 12 Cushioning System After Impact - M37-7

the observations made that if certain features of the truck design are changed, the vehicle can be air-dropped with considerably less risk of damage.

The area in which problems most often occurred was that of the front motor mount and crankshaft pulley. The grease shield on the crankshaft, which passes through a cutout opening in the front supporting yoke, is provided with only a 1/8-in. clearance. Any vertical movement of the engine on its rubber shock mounts in excess of 1/8-in. would bend the grease shield causing it to hit the yoke when the engine was running. The pulley, which is attached to the crankshaft in front of the yoke, has only a 3/32-in. clearance between itself and the yoke. It can be seen from this that any movement of the engine axially in excess of 3/32-in. could damage the pulley causing it to rub on the yoke. This damage would not necessarily render the vehicle inoperable, however the accompaning noise would probably deter use of the vehicle until the extent of damage could be determined. Thus, as in the M151 jeep, the engine support system is vunerable to damage.[4] More clearance and stronger frame members in the vicinity of the motor would eliminate this problem. It is also suggested that on present models, in addition to the standard motor mounts, the motor be supported by nylon webbing or steel straps stretched from one side of the frame to the other. Such devices would help control the displacement of the motor relative to the rest of the vehicle and would provide additional energy dissipation. If the straps are properly designed, it should not be necessary to remove them after a drop as they would be stretched enough during the impact to allow the standard motor mounts to function in a normal manner. It would be very helpful if

hooks or brackets for attaching these straps could be mounted on the frame during fabrication of the vehicle.

It became evident after the first drop that the 1500-lb load of sand bags carried in the bed of the truck could be expected to produce excessive defromation of the bed unless the loading forces could be carried into the frame through some means other than the relatively light metal in the bed. The loadspreader designed and built for this purpose was effective in reducing the bending of the bed. It is suggested that a similar loadspreader be provided during actual drops if a load is dropped with the truck.

Other areas in which damage was observed were the left mount of the gear-reducer housing and the front and rear drive shafts. The damage to the drive shaft was, however, due to impact with load spreaders after rebound, and does not indicate a vehicle design problem. The windows of the truck failed to operate after M37-7 but had only jumped out of the guiding tracks. It is a relatively simple matter to put them back in the tracks.

The difficulty with the voltage regulator could be eliminated by mounting the regulator so that the direction of rotational movement of the points is perpendicular to the direction of the acceleration rather than in the same direction, by improving the shock mounting of the regulator, or by installing a main power switch which disconnects the battery from every circuit during the drop, and is then closed when the vehicle is to be driven.

Typical acceleration records for the M37 are shown in Fig. 13 These accelerations were first recorded on magnetic tape and then rerecorded on paper by running the tape at a reduced speed. The records for the engine are the smoothest because the engine is a large, rigid mass mounted on relatively soft supports.

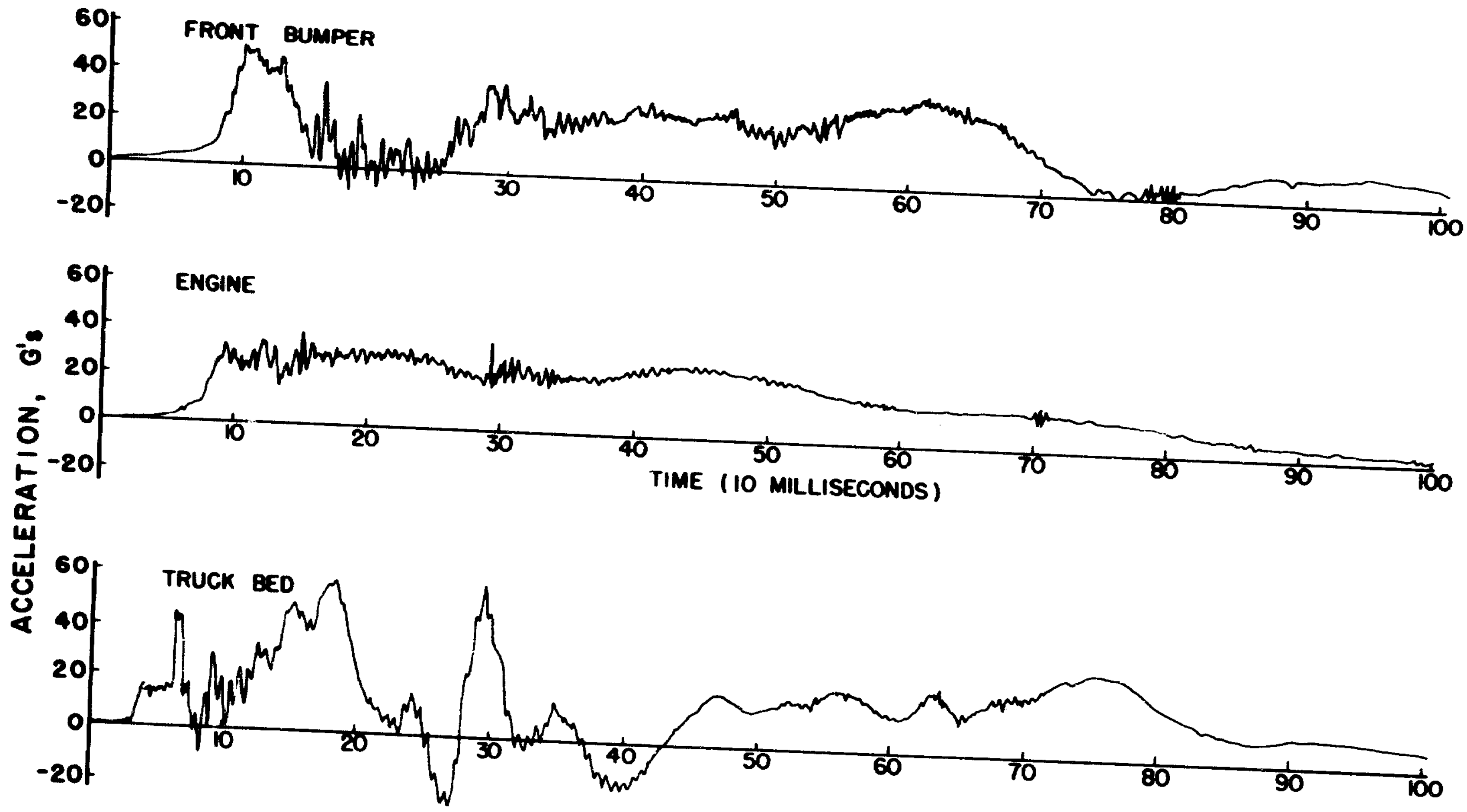


FIG. 13. ACCELERATION RECORDS FOR M37-7 DROP HEIGHT 45.5 FT. ; DESIGN ACCELERATION 30g.

Average accelerations and peak accelerations for all the drops are shown in Table 1. In general, the measured average acceleration is less than the design acceleration as has been observed in previous studies. This is due to the flexibility of the vehicle structure which actually provides some shock mitigation for itself. In Table 1, Column 8, the integral of the acceleration record is shown. This integral should correspond to the impact velocity shown in Column 7. The discrepancies between the impact velocity and the acceleration integration are due mostly to the difficulty inherent in determining just where to stop the integration.

DROP NUMBER	AREA	HEIGHT-FT	DESIGN ACCEL.	PEAK ACCEL.	AVE. ACCEL.	IMPACT VEL.	VEL. CHANGE
1	front	9	18.5g	26.9g	16.2g	24 fps	29.2 fps
1	engine	9	18.5	38.7	18.1	24	28.1
1	rear	9	18.5	No Record	No Record	24	No Record
2	front	20	18.5	34.3	19.2	35.8	36.6
2	engine	20	18.5	43.5	24.6	35.8	40.5
2	rear	20	18.5	No Record	No Record	35.8	No Record
3	front	20	27.5	No Record	No Record	35.8	No Record
3	engine	20	27.5	No Record	No Record	35.8	No Record
3	rear	20	27.5	No Record	No Record	35.8	No Record
4	front	20	27.5	No Record	19.1	35.8	37.8
4	engine	20	27.5	No Record	18.5	35.8	36.6
4	rear	20	27.5	No Record	No Record	35.8	No Record
5	front	30	27.5	39.0	19.0	44.0	49.1
5	engine	30	27.5	26.6	18.6	44.0	47.0
5	rear	30	27.5	No Record	No Record	44.0	No Record
6	front	40	30	36.0	25.5	50.7	51.0
6	engine	40	30	35.0	24.6	50.7	51.5
6	rear	40	30	No Record	21.4	50.7	52.1
7	front	45.5	30	48.1	25.7	54.1	59.8
7	engine	45.5	30	38.5	24.4	54.1	56.5
7	rear	45.5	30	51.9	16.0	54.1	48.5

Table IV. Acceleration Data for 7 Drops of the M37 Truck

CONCLUSIONS

1. The M37 3/4-ton truck can be dropped from a height of 50 ft to land with an impact velocity of 57 fps using essentially the same techniques used for dropping at 25 fps.

2. A cushioning system designed for 30g average acceleration provides adequate protection for the vehicle. This design acceleration should be used even at low-velocity drops to reduce the required stack heights to a minimum.

3. High-velocity drops under adverse wind conditions present no problems under controlled laboratory conditions.

4. Provisions should be made for palletizing the load in the truck bed, if the load consists of concentrated masses.

5. If the rigging is attached to the wheels of the vehicle rather than the platform, the cushioning should be designed so that after the release, the wheels just come in contact with the cushions.

6. A few problems which can be eliminated by suitably redesigning certain parts of the vehicle are:

   a. Interference between crankshaft pulley and front engine-mount cross members.
   b. The closing of voltage regulator contacts during impact.
   c. Lack of ruggedness in structural members in the load area.
   d. Bending of the gear reducer housing support.

7. It is evident from the results of this series of tests that military vehicles can be safely dropped at impact velocities in excess of 50 fps. At the present time, it would be desirable, however, to drop a prototype vehicle of each type, under controlled conditions to determine possible sources of weaknesses, and to develop the details of the cushioning system.

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APPENDIX

Sample Calculations for M37-3

General Approach

There are four essential steps involved in designing a cushioning system to protect a vehicle during test drop:

1. Determine the area of cushioning materials required to provide the desired acceleration levels during impact.
2. Calculate the volume of cushioning material required to absorb the kinetic energy of the falling vehicle.
3. Devise an arrangement of the cushioning material that will keep the vehicle from pitching, or rocking, during impact.
4. Distribute the cushioning material under the vehicle in such a way as to minimize the internal bending moments within its structure

The first three steps are concerned with the rigid body motion of the vehicle. The fourth is concerned with the vehicle as a complex mechanical structure. The vehicle can be ruined regardless of the success of the first three unless this fourth step is taken. Consideration of the vehicle as a complex structure therefore provides the guideline for the overall cushioning design approach.

Vehicle Mass Distribution

Basically the vehicle is a structure built up of concentrated, or lumped, masses connected by flexible beams. During impact, these beams are the most likely parts of the vehicle to fail, as they support the masses and must exert the forces necessary to decelerate them. An obvious way to protect these beams is to attempt to single out the concentrated masses within the vehicle and cushion them independently.

For the design of the cushioning system of the M37 truck, the following masses were considered independently cushionable:

		Assumed Weight
1.	wheels	350 lb each
2.	differentials	480 lb each
3.	gear reducer	300 lb
4.	transmission	200 lb

Once the concentrated masses are cushioned, the remainder of the structure should be cushioned in such a way that the crushing forces during impact will be distributed over the bottom of the vehicle in approximately the same manner as the mass of the remaining structure is distributed throughout the vehicle. The mass distribution for the remainder of the structure of the M37 was assumed to be:

5.	winch	300 lb concentrated load
6.	engine and clutch	600 lb concentrated load

7. 1500 lb dead load — evenly distributed over the bed of the truck

8. structure forward of c.g. (length ℓ_1) — evenly distributed load T_1 lb/ft

9. structure to rear of c.g. (length ℓ_2) — evenly distributed load T_2 lb/ft

The magnitudes of T_1 and T_2 were determined from the static equilibrium relations

$$\Sigma F = 0 = \Sigma W_i - \Sigma R_j$$

$$\Sigma M = 0 = \Sigma W_i \bar{x}_i + \Sigma R_j \bar{y}_j$$

where F = external forces applied to the truck

W_i = weights of truck components

R_j = Reaction forces at the wheels of the truck

M = external moments applied to the truck

$\bar{x}_i$, $\bar{y}_j$ = moment arms about a specified point on the truck

Table V shows the weights, reactions, moment arms, and moments for M37-3.

Now

$$\Sigma F = 0 = T_1\ell_1 + T_2\ell_2 - 2157 \text{ lbs}$$

$$\Sigma M_{CG} = 0 = 4.0T_1\ell_1 - 3.7T_2\ell_2 + 994 \text{ ft lb}$$

And

$$T_1 = 110 \text{ lb/ft}$$

$$T_2 = 180 \text{ lb/ft}$$

Component	Assumed Forces (lbs)	Assumed Moment Arms from C.G. (ft)	Moments (ft lb)
Front Chassis	$T_1 \ell_1$	$4.0 = \frac{\ell_1}{2}$	$4.0\ T_1 \ell_1$
Rear Chassis	$T_2 \ell_2$	$-3.7 = \frac{\ell_2}{2}$	$-3.7\ T_2 \ell_2$
Dead Load (W_{DL})	1500	$-4.0 = (x_{DL})$	-6000
Rear Wheels ($2W_W$)	700	$-4.0 = (x_{FW})$	-4720
Rear Differential (W_{Diff})	480	$-4.0 = (x_{FDiff})$	
Front Wheels ($2W_W$)	700	$5.2 = (x_{RW})$	6150
Front Differential (W_{Diff})	480	$5.2 = (x_{RDiff})$	
Gear Reducer (W_{GR})	300	$.65 = (x_{GR})$	195
Transmission (W_{Tr})	200	$2.75 = (x_{Tr})$	550
Motor & Clutch (W_M)	600	$4.7 = (x_M)$	2820
Winch (W_{Win})	300	$7.5 = (x_{Win})$	2250
Rear Reaction	-4166	-4.0	16650
Front Reaction	-3251	5.2	-16900

Table V. Assumed Static Weights and Moments for M37-3

Cushioning System Design

1. Overall acceleration level - Using the measured average crushing stress for the cushioning material, the overall acceleration level is determined from the following relation:

$$F_c = \sigma_c A = W(G + 1)$$

where F_c = total crushing force

σ_c = measured average honeycomb crushing stress to 70% strain

A = area of supporting honeycomb

W = weight of truck

G = acceleration level measured in "g's"

for σ_c = 7800 lb/ft^2

W = 7420 lbs

G = 27.5g's

$$A_{total} = \frac{7420 \times 28.5}{7800} = 27.4 \text{ ft}^2$$

2. Crushing stack height - From a work energy balance, the stack height required to provide the volume of honeycomb necessary to cushion the vehicle is determined from

$$A \times \sigma_c \times 0.7H = W(h + 0.7H)$$

σ_c = average crushing stress to 70% strain for honeycomb used

H = crushing stack height

h = drop height = 20 ft

A = honeycomb area

$$7800 \times 27.4 \times 0.7H = 7420\ (20 + 0.7H)$$

and

$$H = 1.03 \text{ ft}$$

which requires a minimum of four 3 in. pads.

3. Distribution - The individual honeycomb stack areas add to meet the total area requirements. Since the concentrated masses were cushioned independently, the corresponding stack areas were determined directly from:

$$\sigma_c A = W(G + 1)$$

a). wheels

$$7800\ A = 350 \times 28.5$$

$$A_w = 1.29\ ft^2$$

b). differentials

$$7800\ A_{Diff} = 480 \times 28.5$$

$$A_{Diff} = 1.78\ ft^2$$

c). gear reducer

$$7800\ A_{G.R.} = 300 \times 28.5$$

$$A_{G.R.} = 1.10\ ft^2$$

d). transmission

$$7800\ A_{Tr} = 200 \times 28.5$$

$$A_{Tr} = 0.74\ ft^2$$

The placement of the remainder of the area in the cushioning design is determined to a large extent by the understructure of the vehicle since places must be found where the structure is reasonably strong and where there is enough room to place the cushioning. Beginning with possible placement positions, the design must then be completed to satisfy the 3rd and 4th steps given on page 41.

For the M37 truck, the cushioning placement positions were selected for the distributed loads at the points occupied by A_1, A_2, A_3, A_4 indicated on Fig. 6. In order to minimize the internal bending moments in the truck structure, the truck was conceptually divided into two free bodies; the region forward of the center of gravity, and the region to the rear of the center of gravity. Moments and forces were balanced independently for these two regions so that from a rigid body standpoint, there would be no bending moment within the truck at the center of gravity. The grouping of stacks in this manner also assured a relatively even distribution of forces according to mass supported. Using the assumed weight distribution of the truck, plus the chosen placement positions for the stacks 1 through 4, the magnitudes of the areas required at these four positions were solved for, using D'Alembert's principle.

<u>Front section</u> (See Fig. 6, Table II and Table V)

$$\Sigma[F_{cush} - (G+1)W] = 0$$

This equation in expanded form becomes

$$\sigma_c(A_1+A_2+A_{Tr}+A_{GR}+2A_W+A_{Diff}) - (G+1)[T_1\ell_1+(W_{Diff}+2W_W)$$
$$+W_{GR}+W_{Tr}+W_M+W_{Win}] = 0$$

$$7800(A_1+A_2) + 7800(0.74 + 1.10 + 1.29 + 1.29 + 1.78)$$
$$-28.5(110 \times 8.0 + 1180 + 300 + 200 + 600 + 300) = 0$$

$$7800(A_1+A_2) = 51{,}100$$

$$A_1 + A_2 = 6.65 \text{ ft}^2 \qquad (1)$$

From the previously stated requirement of zero moment about the CG of the truck

$$\Sigma[M_{cush} - (G+1)W\bar{x}]_{CG} = 0$$

$$\sigma_c[A_1x_1+A_2x_2+(Ax)_{Tr}+(2A_W+A_{Diff})x_{FW}+(Ax)_{GR}]$$
$$-(G+1)[\frac{T_1\ell_1^2}{2}+(2W_W+W_{Diff})x_{FW}+(Wx)_{GR}+(Wx)_{Tr}+(Wx)_M+(Wx)_{Win}] = 0$$

Solving for the moments about the C.G. of the truck.

$$\Sigma(M - ma\bar{x}) = 0$$

$$7800(A_1\bar{\ell}_1+A_2\bar{\ell}_2) + 7800[0.74 \times 2.75 + (2 \times 1.29 + 1.78)5.2$$
$$+ 1.10 \times .65]$$
$$-28.5[110 \times 8 \times 4 + 1180 \times 5.2 + 300 \times 0.65 + 200 \times 2.75$$
$$+ 600 \times 4.7 + 300 \times 7.5] = 0$$
$$A_1\ell_1 + A_2\ell_2)7800 = 250{,}000$$

for $\ell_1 = 7.0$ ft , $\ell_2 = 1.9$ ft

$$7A_1 + 1.9A_2 = 31 \qquad (2)$$

from eq's. (1) and (2)

$$A_1 = 3.59\ ft^2$$

$$A_2 = 3.06\ ft^2$$

<u>Rear Section</u>

$$7800(A_3+A_4) + 7800(2(1.29) + 1.78)$$

$$-28.5(1500 + 1180 + 180 \times 7.5) = 0$$

$$A_3 + A_4 = 10.18 \qquad (3)$$

for moments

$$7800(A_3\ell_3+A_4\ell_4) - 28.5(1500 \times 4 + 1180 \times 4.0 - 180 \times 7.5 \times 3.7)$$

$$+ 7800(2(1.29) + 1.78)4.0 = 0$$

$$1.2A_3 + 7.25A_4 = 39.6 \qquad (4)$$

and from eq's (3) and (4)

$$A_3 = 5.56\ ft^2$$

$$A_4 = 4.53\ ft^2$$

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13. ABSTRACT

Seven drops of the M37 3/4-ton truck have been made at impact velocities up to 56 fps, and at design accelerations as high as 30g. The cushioning system used for each drop is described and the damage sustained by the vehicle is discussed. It is concluded that this vehicle can be dropped at impact velocities up to 50 fps without any damage, if a properly designed cushioning system is used.

Recommendations for improvements, from the aerial delivery standpoint, in the design of the vehicle are included. A detailed description is given of the procedure that should be followed in the design of a cushioning system.

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Cushioning	8		6			
Cargo vehicles	9		7			
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